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Weld Cladding of HY-80 Steel with Monel

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Contract #W7707-008471/001/HAL

Defence R&D Canada

Contractor Report
DREA CR 2001-081
July 2001

National Defence Défense nationale

Canada

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Approved by

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Approved for release by

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Chair, Document Review Panel

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Abstract

To produce specimens for the evaluation of dilution effects in Monel cladding of HY-80 steel, shielded metal arc and gas metal arc welding were used to clad coupons of HY-80 with Monel. A range of dilutions from less than 3% iron to in excess of 15% iron were achieved. Monel sheets were welded around the unclad faces of some coupons, to produce specimens suitable for long-term corrosion studies without galvanic effects.

Résumé

Pour obtenir des échantillons pouvant servir à évaluer les effets de dilution lors du surfaçage au monel de l'acier HY-80, on a utilisé le soudage à l'arc avec électrodes enrobées et le soudage à l'arc sous gaz protecteur pour plaquer des coupons de HY-80 au monel. On a obtenu un intervalle de dilutions allant de moins de 3 % à plus de 15 % de fer. Les feuilles de monel ont été soudées sur les surfaces non plaquées de certaines éprouvettes, pour obtenir des échantillons pouvant servir aux études de corrosion à long terme sans effets galvaniques.

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Executive summary

Introduction: Some of the valves on the Victoria class submarines are made from Q1N steel (British version of HY-80) clad with monel for corrosion protection. Standard British practice has been to restrict dilution of the monel deposit by iron from the base material to 3%, which requires multiple weld layers, and increases the difficulty and cost of repairs. The original studies and rationale on which the practice was developed is unavailable, but recently published data related to copper nickel boat hulls suggest a 10% dilution is acceptable. In light of this inconsistency, a study to assess the affect of iron dilution on monel clad performance has been started. The work includes consideration of weld dilution measurement, welding studies, weldment characterization and short and long term corrosion studies on various weldments. This report describes the welding of coupons used in the study.

Principal Results and their Significance: Coupons of HY-80 were clad with multiple layers of monel using two processes, shielded metal arc and gas metal arc welding and a range of procedural variables. Conditions used are representative of actual welding conditions used in valve cladding and repair and have been shown to give dilutions from less than 3% to in excess of 15% iron.

Future and Related Work: Metallographic analysis, laboratory corrosion studies and long-term corrosion studies on the coupons are in progress.

Morrison, Kevin; 2001
Weld Cladding of HY-80 Steel with Monel
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Defence Research Establishment Atlantic

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Sommaire

Introduction : Certaines des valves des sous-marins de classe Victoria sont composées d'acier Q1N (l'équivalent britannique de l'acier HY-80) qui sont plaquées de monel afin de les protéger de la corrosion. En Grande-Bretagne, la pratique normale consiste à limiter à 3 % la dilution du dépôt de monel par le fer du matériau de base, ce qui exige de multiples couches de soudure et accroît la difficulté et le coût des remises en état. Les études d'origine et le motif qui ont servi à élaborer la pratique en question ne sont pas disponibles, mais des données publiées récemment, portant sur les coques de navire en cuivre-nickel, semblent indiquer qu'une dilution de 10 % est acceptable. Ces valeurs contradictoires ont été à l'origine d'une étude visant à évaluer les effets de la dilution par le fer sur la performance du surfaçage au monel. Les travaux comprennent des mesures de la dilution de la soudure, des études de soudage, la caractérisation des assemblages soudés et des études de corrosion, à court et à long terme, sur différents assemblages soudés. Le présent rapport contient la description du soudage des éprouvettes utilisées au cours de l'étude en question.

Importance des principaux résultats : Les éprouvettes d'acier HY-80 ont été plaquées avec des couches multiples de monel, en utilisant deux procédés distincts, soit le soudage à l'arc avec électrodes enrobées et le soudage à l'arc sous gaz protecteur, et en faisant varier un certain nombre de paramètres du mode opératoire. Les conditions d'essai sont représentatives des conditions de soudage réelles, lors du placage et de la remise en état de valves, et il a été démontré que les dilutions obtenues se situent entre moins de 3 % et plus de 15 % de fer.

Travaux futurs et connexes : On effectue présentement l'analyse métallographique des éprouvettes, ainsi que des études de corrosion en laboratoire et des études de corrosion à long terme.

Morrison, Kevin 2001
Surfaçage au monel de l'acier HY-80
DREA CR 2001-081
Centre de recherches pour la défense – Atlantique

NU-TECH
Precision Metals

Weld Cladding of HY-80 Steel With Monel

Submitted to:

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Defence Research Establishment Atlantic

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Contract #W7707-008471/001/HAL

NTPM #40-1613

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Weld Overlay of HY80 Submarine Steel

1.0 Introduction

To evaluate the effects of welding process, consumables and parameters for Monel overlayed HY80 steels exposed to seawater environments, weld overlay test samples were produced at Nu-Tech for evaluation at DREA The welding procedure design objective was to identify and apply welding procedures and techniques which would provide a range of weld deposit dilution levels using the shielded metal arc (SMAW) and pulsed gas metal arc welding (P-GMAW) processes.

2.0 Scope

The overall program requirements were as follows:

1) Review the open literature to identify welding procedure related parameters, which affect the corrosion performance of overlayed weld metal.
2) Develop SMAW and P-GMAW welding procedures, which would provide Monel overlayed HY80 sample plates with a variety of dilution levels (<3% up to ≡15%). Representative samples were to be assessed and approved by DREA before carrying out full sample production.
3) Produce Monel overlayed HY80 corrosion samples using the procedures approved by DREA.
4) Document all welding procedure details for duplication in future corrosion studies and/or for actual overlay applications.

3.0 Literature Review

3 1 Introduction

DREA selected literature on the topic of overlay welding. Nine articles were forwarded to Nu-Tech for review. The objective was to identify overlay welding procedural guidance which would lead to optimizing productivity, dilution and quality for Monel overlay welding of steels. This information, together with Nu-Tech's own experience with overlay welding, formed the basis of the overlay procedures developed and applied in this program.

The specific areas where the experience of others was sought were as follows:

1) metal preparation
2) welding processes
3) consumables
4) welding parameters and techniques
5) overlay finishing
6) inspection

Although most of the papers reviewed offered information on the metallurgical consequences of overlaying, this information was considered outside the scope of this review unless it was relevant to welding application

3.2 Metal Preparation

Cleanliness was considered the single-most important requirement for successful welding of nickel alloys [1, 2, 3].

The best method of preparing base metals for overlay would be to machine the part to be overlayed. This is the standard procedure for the QIN seawater system castings used in the Victoria Class submarines [2]. Castings require additional care in preparing the surface since exposed casting defects can lead to overlay weld defects which can reduce corrosion resistance in these areas. The procedure used on the Victoria Class castings would, therefore, include the following steps:

1) Machine the surface to the required dimensions.
2) Inspect surfaces using liquid penetrant inspection (LPI)
3) Excavate any defects found by LPI.
4) Use the gas tungsten arc (GTAW) or shield metal arc (SMAW) welding processes to fill excavated cavities with AWS ERNiCu-7 (GTAW) or AWS ENiCu-7 (SMAW) filler metals.
5) Re-machine or condition locally to the required dimensions.
6) LPI repaired areas.
7) Apply the overlay weld.

To avoid weld discontinuities and weld metal transfer instability during welding, the metal must be clean and dry before welding. This can be achieved by using an alcohol or acetone wipe prior to arc initiation.

For the pulsed gas metal arc welding (P-GMAW) process used in this program and for other gas shielded processes, metal cleanliness is a critical parameter in ensuring that weld deposition occurs with stable conditions Arc instabilities caused by surface contaminants (greases, oil, moisture and oxides) often result in weld defects.

3.3 Welding Processes

The processes used in weld overlaying of marine materials include [1,2,3,4,5].

- plasma arc welding (PAW); hot & cold wire additions
- gas tungsten arc welding (GTAW); hot and cold wire additions
- shielded metal arc welding (SMAW)
- submerged arc welding (SAW); including strip clad SAW
- gas metal arc welding (GMAW)
- oxy-acetylene welding (OAW)

The welding processes selected for use in the current program include the pulsed variation of the GMAW process and SMAW. It is well understood that the SMAW process offers the greatest flexibility since the equipment is simple, rugged and portable while being familiar to the widest range of welders Positional welding is also possible with smaller diameter electrodes (≤4 0mm)

PAW, OAW, GTAW and the SAW process have all been used for overlay work on marine materials. The P-GMAW process offers a good balance of versatility, control of dilution, productivity, capital cost and facility expansion when compared to the alternative processes when overlaying pipe systems [4].

Scomak Engineering manufactured overlayed pipes, flanges and fittings for corrosion resistant applications and selected the synergic P-GMAW process after careful consideration of alternatives since it offered a wide range of deposition rates, provided good dilution control and was able to accommodate restricted access and positional welding requirements for both mechanized and manual welding.

It was not uncommon that dilution levels of less than 5% be specified within 3mm of the substrate fusion line for single layer deposits. This was a common requirement at Scomak when overlaying the nickel based 625 alloy onto steel. Although actual overlay welding parameters were not disclosed, it was implied that to meet this requirement considerable process experience was required to avoid interface fusion defects. This suggests that the welding energy levels used were at the low end, where penetration is minimal for this free flight P-GMAW metal transfer process.

3.4 Consumables

Although the weld metal composition was fixed in the current program, the literature was reviewed to determine if certain diameters of consumables or particular shielding gas compositions were preferred

No information was available on the effect of wire diameter on dilution. The Inco literature, however, generally suggests that a 1.6mm diameter wire be used for spray transfer, 0.9mm for short circuit and a 1.2mm diameter when using pulsed spray transfer.

Recommended shielding gas compositions for Ni alloys include Ar and Argon 75%/Helium 25 [1]. Helium additions of 25% were reported to provide wider, flatter weld beads with less penetration (dilution) than pure Argon

3 5 Welding Parameters and Techniques

3.5 1 Welding parameters and welding techniques are critical for control of weld defects and diluted deposition chemistry. Process control in the first layer is the most critical since this is when the pick-up of iron from the steel substrate occurs

3.5 2 Shielded Metal Arc Welding (SMAW)

For the SMAW process the range of power settings is limited as are the techniques. The dilution rate expected for the SMAW process is 20% to 40% depending on the technique used. The technique could include arc length, travel angle, travel speed, work angle, weave pattern and the location the arc is being directed relative to previous beads. The following recommendations are presented for SMAW overlay with ENiCu-7:

1. Amperage should be in the lower half of the recommended range. The recommended ranges for ENiCu-7 electrodes are listed here [1].

Electrode Size (inches)	DC Amperage	DC Lower Range
2.4 (3/32)	55-75	55-65
3.2 (1/8)	75-110	75-90
4.0 (5/32)	110-150	110-130
4.8 (3/16)	150-190	150-170

2. The major arc force should be directed at the fusion line of the previous bead so that the weld metal will spread onto the steel with only minimum weaving of the electrode.

3. If deposits are spread wide by weaving, the weld height will be reduced, requiring more layers, and dilution will be higher than if minimal weaving was used.

4. The underbead contour of the overlay (penetration pattern on a transverse weld macro-section) should be as consistent as possible. An uneven penetration profile indicates excessive iron dilution and bend samples can develop tears or cracks at the first layer interface.

5. For the first two layers the weld overlap with the previous bead should be 30% to 50%.

3.5.3 Gas Metal Arc Welding (GMAW)

Dilution rates for the GMAW process can range from 10% - 50% depending on the metal transfer mode used, the power level and the technique

In selecting low dilution GMAW welding parameters and techniques, the objective would be to use just enough energy to obtain adequate fusion with the substrate and previously deposited beads. The surface contour of the overlay must also be smooth between individual beads to avoid fusion defects in subsequent layers

Overlays are usually produced with mechanized equipment using gun oscillation [1]. The preferred oscillation pattern is one that does not hesitate at the sides. Oscillation provides a much wider and flatter bead than the stringer bead (straight line) technique with less dilution. Since hesitation at the weld edges is

not desired because of the associated deeper penetration (dilution), the welding conditions must provide good puddle wetting to ensure fusion in the weld toe areas

Iron dilution is also affected by oscillation width where wider welds will have lower Fe dilution. The alignment of the wire relative to the previous bead is approximately at the toe of the previous bead which will provide a level deposit. This alignment is easily adjusted for the GMA welding process since the puddle is in full view.

The dilution levels reported in the Inco literature, which uses a first layer of ERNi-1, indicates 7.8% Fe in the first layer of ERNiCu-7 and 2.9% for the second layer of ERNiCu-7.

ERNi-1 filler metal is typically recommended as a buffer layer to avoid hot cracking caused by high sulphur and phosphorous steel substrates and by high levels of Fe dilution. The ERNi-1 is reported to be capable of tolerating higher levels of Fe dilution without fissuring.

3.6 Interpass Cleaning Surface Finishing

Interpass and interlayer cleaning during welding is required to avoid weld defects and to accommodate inspection. The final deposit is also finished before going into service.

Methods of cleaning and finishing include wire brushing, grinding, abrasive shot blasting, machining and pickling.

Interpass cleaning of surface oxides which may compromise fusion for the subsequent layer are best removed by wire brushing using dedicated stainless steel wire brushes for light oxides, and grinding for tightly adhered oxides. Dedicated aluminum oxide grinding discs are recommended for heavy oxide removal Grinding can also be used to remove geometric irregularities, which may cause fusion defects in the next layer.

Light grinding and wire brushing may also be necessary between layers if dye penetrant inspection is called for.

3.7 Control of Iron Content in Ni alloy Weld Overlays

Final preparation of overlayed areas is usually done by machining the component to the required dimensions. There was no guidance in the open literature on the performance of as deposited surfaces. Final machining of Monel overlayed Q1N steels for the Victoria class submarines requires that the Fe content of exposed surfaces should not exceed 3%. This is to avoid pitting as a consequence of impingement attack or reduce general corrosion resistance due to the formation of complex iron chromium cuboids

Meeting the above requirement in practice would require the development and qualification of overlay procedures which produce the required maximum dilution and designing the pre-machined dimensions to ensure that the final machined surface coincides with the 3% Fe maximum portion of the overlay Controlling the qualified procedure in actual work would be critical, since minor variations in process parameters and techniques are likely to increase Fe dilution (e.g tip to work distance, travel speed, oscillation width etc.).

Compliance with a 3% maximum iron content will require two or more layers of weld metal depending on the process, procedures and consumables used. Specifying a low Fe consumable is also recommended since an AWS ERNiCu-7 has a maximum allowable iron content of 2.5%. When considering the cost of welding consumables, pre-machining, welding, inspecting, repairing when necessary, final machining and the added distortion risk of more than two layers, the benefit of a two layer technique versus a three layer technique is significant It is of interest that the steady DC non-pulsed spray welding procedure reported in the Inco literature used a 1.6mm diameter electrode wire and just met the 3% Fe maximum requirement with three layers. Based on the submerged arc welding data presented in the same Inco literature, three layers would also be required with this process. The hot-wire plasma arc welding data suggest 3% maximum Fe is easily met with two layers due to the excellent control of dilution available with this process.

As mentioned earlier, pulsed gas metal arc welding has also been used to apply nickel based 625 overlay to steel substrates with less than 5% dilution in the first layer. These results are slightly better than that reported in the Inco literature for the first layer of a hot wire PAW deposit which resulted in 5.5% Fe. The P-GMAW process is a more attractive option than hot wire PAW since the GMAW equipment is considerably less complicated, less expensive to purchase and more flexible for applications with restricted access since wire additions into the puddle are integral to the arc with P-GMAW. The PAW process may be more consistent in continuous overlay operations, however, since the welding energy path does not rely on a dynamic mechanical path (wire feed, gun liner and contact tip).

For the SMAW process, where dilution can range from 20% - 40%, the number of layers required could be three or more. A conservative approach on the number of layers specified may need to be applied for this process since the actual dilution level is strongly influenced by the welder and the techniques used Welder training which focuses on the effect that welding technique has on dilution for the first and second layers will help to minimize the number of layers needed.

3.8 Overlay Process Inspection

For overlay of Q1N steel valve bodies for the Victoria class submarines it is recommended that NDE be carried out during and upon completion of overlay welding to ensure that the required fusion is being obtained and that welds meet design quality requirements. The recommended inspection methods include liquid penetrant inspection (LPI) and ultrasonic inspection (UT) The recommended inspection schedule would be as follows:

1) visual examination of each weld bead
2) LPI of the first layer
3) LPI and UT after the initial rough machining of the final layer
4) final LPI of the finished machined part
5) chemical composition analysis of the final machined surface

3.9 Summary

In order to develop welding procedures which provide a range of weld metal dilution levels for corrosion testing at DREA, the following guidelines from the open literature were incorporated into the Monel overlay corrosion samples.

SMAW
1) use current setting on the low end of the usable range for each diameter
2) direct the arc towards the previously deposited bead
3) overlap the previously deposited beads 30% to 50%
4) weaving of the electrode was not used

P-GMAW (low dilution)
1) use torch oscillation without toe area hesitation
2) use lowest practical energy level while maintaining substrate and previous bead fusion
3) use the He bearing gas for improved puddle wetting behaviour
4) overlap previous bead to obtain flat overlay profile to assist interlayer inspection and second layer deposition without grinding

P-GMAW (high dilution)
1) use stringer bead technique
2) use higher energy parameters
3) adjust travel speed to position the arc towards the leading edge of the molten puddle to reduce the metal under the arc

4.0 Corrosion Sample Procedure Approval

4.1 As stated earlier, the program objective was to determine the critical weld overlay ferrite level which, if exceeded, would result in unacceptable corrosion properties in seawater systems. To this end, a range of overlay weld compositions were required for corrosion testing at DREA The target composition range was less than 3% Fe to approximately 15% Fe

Three samples were forwarded to DREA for confirmation that the overlay procedures developed at Nu-Tech would encompass the required Fe range

One sample was representative of the 4 0mm diameter SMAW procedure with 2 layers. The second sample was representative of the higher energy P-GMAW stringer bead (no-oscillation) procedure and the third sample represented the low energy P-GMAW procedure which used oscillation.

In an attempt to isolate any compositional gradients and to expose reheated weld metal morphologies, the 4.0mm SMAW and the higher energy P-GMAW samples were provided with .5mm x 32mm long machined step surfaces as illustrated in figure 1. The low energy P-GMAW sample was forwarded after the results of the other two plates determined that the low end of the target dilution range had not been achieved. This sample was approximately 32mm long with a single and double layer portion of weld.

The results of overlay surface chemical analysis performed at DREA are shown in tables 1 & 2. The results suggest the Fe dilution range of less than 3% Fe to approximately 15% Fe was achieved at the welding energy/technique extremes and that the full range should be represented by the intermediate procedures.

5.0 Monel Overlayed HY80 Welding Procedure Development and Corrosion Sample Preparation

5.1 Base Metal

HY80 steel base metal was supplied to Nu-Tech as 150 x 305 x 25mm thick thermally cut plates. The surfaces to be overlayed were prepared at Nu-Tech by machining <1.6mm off the surface to provide a clean surface for welding

5.2 Shielded Metal Arc Welding Consumables

Three different electrode diameters of AWS ENiCu-7 were selected for use in the current program. The electrode sizes were chosen to represent a range of application needs including positional welding. The electrode diameters used were 3.2, 4.0 and 5.0mm. The same diameter electrode was used on each of the three SMAW corrosion test plates.

The composition of each electrode is shown in Appendix A.

5.3 Gas Metal Arc Welding Consumables

Only the 1.2mm diameter solid ERNiCu-7 wire was used for overlay in this program. This wire was selected over smaller diameters since wire feed speeds are lower, thereby, reducing wire drive system wear problems while providing positional capabilities. Larger diameter wires would also operate at lower current densities than smaller wire and, therefore, potentially offer reduced dilution for a given weld size However, they may not provide the desired fusion characteristics at low power levels.

The composition of the 1.2mm diameter wire used for all GMA welding in this program is shown in Appendix A

Four shielding gas compositions were evaluated during P-GMAW procedure development. These included pure Argon, 25%He/75%Ar, 50%He/50%Ar and 75%He/25%Ar. The 25%He/75%Ar provided the most stable arc and weld puddle control using the standard synergic programs available. Attempts to develop custom programs, which may have improved the appeal of the higher Helium gases were not attempted based on the acceptable performance with the readily available programs.

5.4 Welding Procedures

5.4.1 SMAW

Unlike continuous wire feed welding processes, the range of techniques and power settings is limited for the manually applied SMAW process This process, however, offers the greatest flexibility for both field and shop applications Optimum amperage, travel, work angle and arc length were selected for each diameter by trial welding on C-Mn steel plate. All overlay welding was carried out in the flat position.

A custom electrode guide was attached to the automatic carriage/track arrangement to control the deposit within a narrow range of travel speed

The final parameters used to produce overlayed corrosion samples are presented in Appendix B.

5.4.2 Pulsed Gas Metal Arc Welding Procedures

A 1.2mm diameter ERNiCu-7 consumable wire and 25 He/75 Ar shielding gas mixture was selected for all P-GMAW overlay welding. This combination worked well using the 1.2mm C-Mn steel synergic welding program supplied with the Miller Maxtron 450 and the Miller 64 m feeder which was used for all P-GMAW welding. A 450 amp Bernard, watercooled welding torch was mounted to a Gullco travel carriage/track arrangement to provide consistent welding speed A Gullco torch oscillator was also used with two of the three procedures developed

The Welding parameters used to produce corrosion test samples represent the following approaches:

1) low heat input, low dilution with oscillation
2) medium heat input, higher dilution with oscillation
3) same as above without oscillation

The final three P-GMAW procedures, which were all applied in the flat position of welding, are presented in Appendix B.

All of these procedures are considered easy to apply and were designed to accommodate a range of application requirements.

The low wire feed (150 IPM) procedure represents the lower end of the energy range where weld fusion and wetting is assisted with oscillation. Without oscillation the weld would be somewhat ropey in appearance with borderline fusion behaviour. This low energy approach (with wire oscillation) would serve well when depositing on the recommended machined surfaces and where oscillation is available. These parameters are not recommended without oscillation.

The higher 225 IPM wire feed speed procedures represents higher energy (higher dilution) approaches where a more aggressive arc is available to ensure weld fusion. The higher energy with the associated wetter puddle conditions ensure fusion without the use of oscillation.

The oscillation provided good control of weld shape and would be useful when the substrate surface is not smooth and free of oxides. Oscillation helped to reduce the crown of the weld by spreading out the deposit, making the tie-ins with previous beads smooth. This is particularly beneficial in providing a smooth surface for the subsequent layers of overlay, since grinding or machining of the first layer would not be required.

Although outside the scope of this program, variations of the above procedures can be used to minimize dilution in the first layer while increasing deposition rates for subsequent layers. For example, the low dilution 150 IPM wire feed speed procedure could be used for the initial layer and the higher WFS procedure for subsequent layers Higher wire feed speeds and travel speed combinations than that used here are also possible. The dilution effect of procedure combinations or the use of high energy welding would need to be determined before being used.

6.0 Monel Overlay Sample Production

6.1 Three 150mm x 305mm x 25mm thick machined HY80 plates were overlayed using the SMAW process and 3.2, 4.0 and 5.0mm diameter electrodes. A three layer overlay was produced for each plate using one diameter electrode per overlay and welding in the 305mm length (see figures 2-4). A single 150mm x 305mm x 25mm thick machined HY80 plate was used for three separate P-GMAW procedures. 50mm wide two layer overlays were deposited beside each other down the 305mm length (figure 5). In order to expose a range of overlay compositions and weld morphologies (reheated and cast) to seawater conditions, samples were machined in 0.5mm steps along the 305mm length. The length of each step was 32mm to accommodate the probe size used for surface chemistry analysis (see figure 1).

In order to isolate the corrosion performance of Monel overlays by eliminating the protective effect of the steel substrate, the exposed HY80 portions of the test plate were encased in 3.2mm thick Monel sheet metal. Sheet metal edges were welded autogenously (no filler) except the corners (25mm long welds) and the

joint between the overlay and the sheet metal. ERNiCu-7 filler was used with the P-GMAW process at the overlay/sheet metal joint. GTAW and ERNiCu-7 was used at corner locations.

7.0 Conclusions

7.1 Following a review of the open literature and the development of SMAW and P-GMAW procedures at Nu-Tech, Monel overlay corrosion samples were produced, which will provide a range of iron dilution levels for corrosion performance evaluation at DREA. A total of six procedures were developed, three for the SMAW process and three for the P-GMAW process.

Corrosion overlay welds samples were machined and the exposed HY80 steel base metal was encased in 3.2mm thick Monel sheet.

All welding procedures have been documented and form a part of this report

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TABLE 1

Iron Content of High Dilution P-GMAW And Medium Energy SMAW Overlay Welds

Step Number	GMAW (W/%Fe)*		SMAW (w%Fe)**	
1 Thinnest	14.3		17.4	
2	15.2		16.7	
3	15.8		16.6	
4	15.0		8.51	
5	5.62		6.28	
6	5.53		5.34	
7	5.46		6.17	
8	4.36		7.16	
9 Thickest			6.32	
	±0.5 due to actual variation of composition on surface over three analysis		±0.5 due to actual variation of composition on surface over three analysis	
NBS Standard 2.1 iron		2.14 Before		2.3 After

* P-GMAW using high energy procedure without oscillation (2 layers)

** SMAW procedure using 4.0mm diameter electrodes (2 layers)

TABLE 2

Iron Content of Low Dilution P-GMAW Overlay Weld

DREA/DOCKYARD LABORATORY
EMISSION SPECTROMETER
ANALYSIS REPORT

Item Analyzed: Monel on HY80 /2 layer

Lowest Dilution

NI-01/Ni - Base Sample : 150-5 03/23/2001 15:0

Grade No : -/-
Grade Name : -/-

Grade Identification - Average of 3 measurements / Concentrations

Si	Mn	Cr	Mo	Fe	V	W
0.22	2.35	<0.0002	0.024	1.06	<0.002	<0.00
Cu	Al	Co	Nb	Ti	Mg	Ni
30.0	0.10	0.57	0.077	1.42	<0.002	64.2

Remarks:

Item Analyzed: Monel on HY80 /1 layer

Lowest Dilution

NI-01/Ni - Base Sample : 150-5 03/23/2001 15:0

Grade No : -/-
Grade Name : -/-

Grade Identification - Average of 3 measurements / Concentrations

Si	Mn	Cr	Mo	Fe	V	W
0.23	2.33	<0.0002	0.025	3.78	<0.002	<0.0
Cu	Al	Co	Nb	Ti	Mg	Ni
-32.4	0.11	0.53	0.078	1.44	<0.002	59.

Remarks:

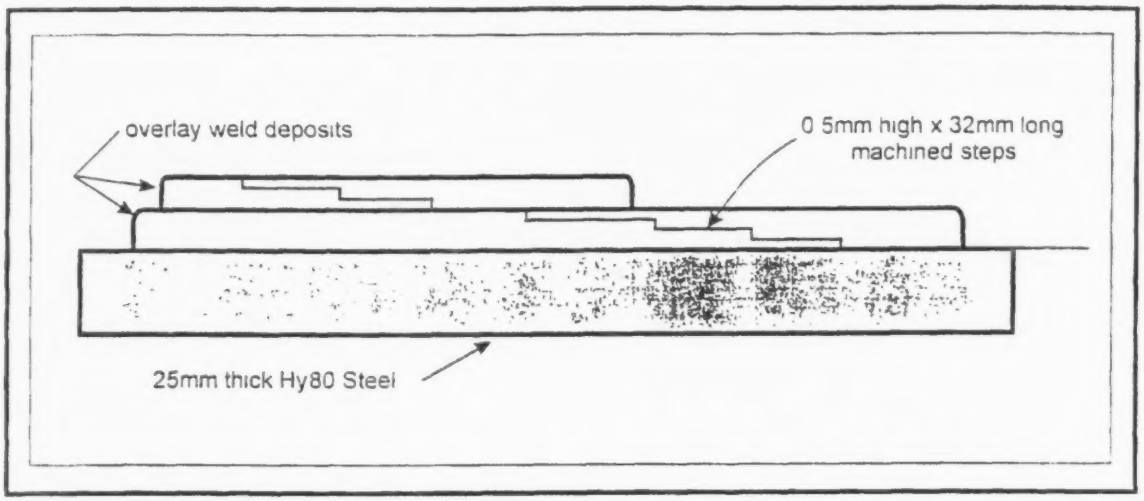

FIGURE 1

Step Machining Preparation of Overlay Corrosion Samples

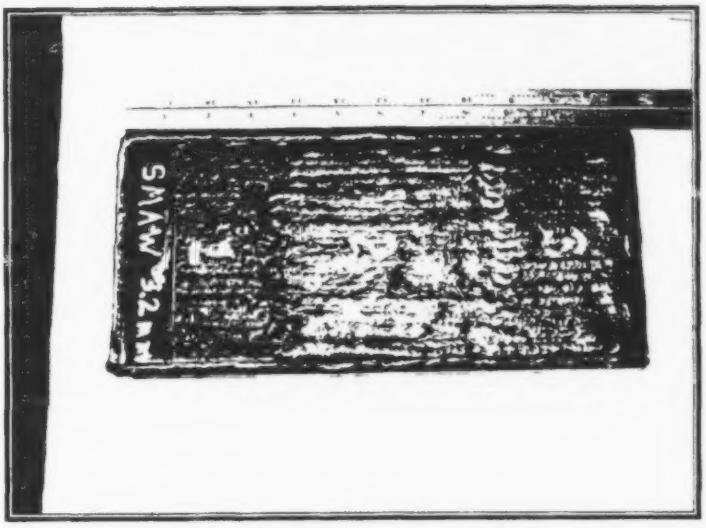

Figure 2 MANUAL SMAW OVERLAY WELD CORROSION TEST SAMPLE PRODUCED USING 3.2mm DIAMETER ERNiCu-7 ELECTRODES

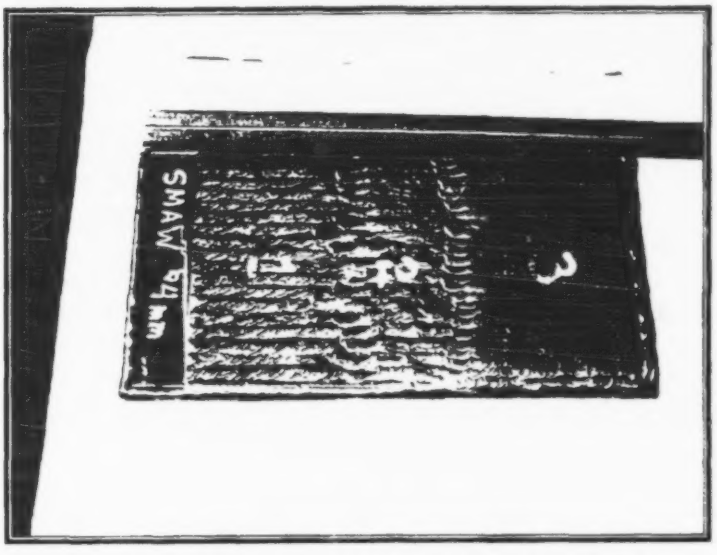

Figure 3 MANUAL SMAW OVERLAY WELD CORROSION TEST SAMPLE PRODUCED USING 4.0mm DIAMETER ERNiCu-7 ELECTRODES

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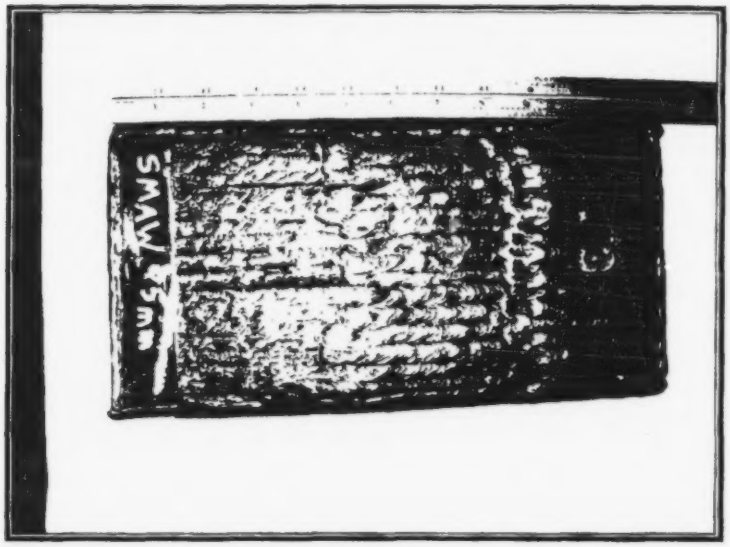

Figure 4 MANUAL SMAW OVERLAY WELD CORROSION TEST SAMPLE PRODUCED USING 5.0mm DIAMETER ERNiCu-7 ELECTRODES

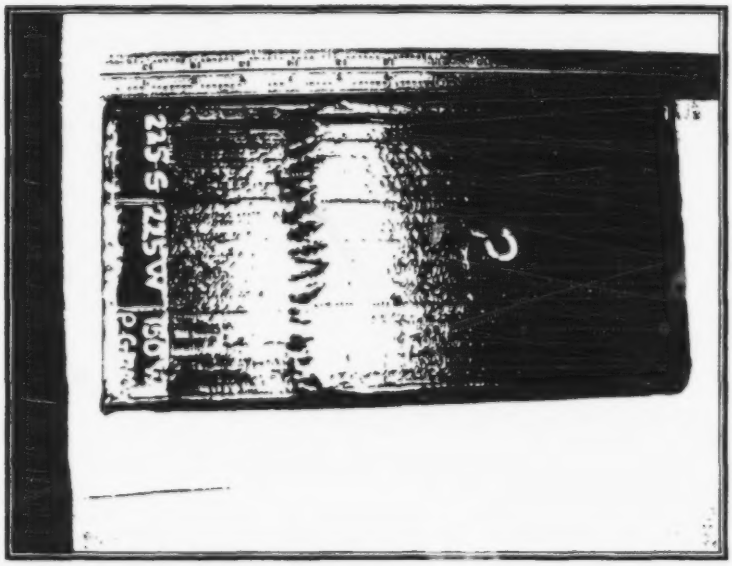

Figure 5 PULSED- GMAW ENiCu-7 WELD OVERLAY CORROSION TEST SAMPLE SHOWING THREE SEPARATE 2 LAYER PROCEDURES (50mm WIDE EACH) ON ONE 150 x 305 x 25mm THICK HY80 PLATE

APPENDIX A

Welding Filler Metal Material Test Reports

NORCROSS GA 770-923-0353 FAX 770-923-0703
NORCROSS GA (WELDING) 770-923-6447 FAX 770-923-9117
UNION IL 815-923-2131 FAX 815-923-2126
UNION IL (WELDING) 815-923-2131 FAX 815-923-7242

TECHALLOY Company

BALTIMORE MD 410-633-9300 FAX 410-633-0033
NORTHAMPTON MA 413-584-3564 FAX 413-584-5289
HOUSTON TX 713-466-1000 FAX 713-466-7425
PERRIS CA 909-657-2105 FAX 909-943-5061

BALTIMORE WELDING DIVISION
2310 CHESAPEAKE AVE BALTIMORE MD 21222-4099
TEL: 410-633-9300 FAX: 231-628-1074

CERTIFIED MATERIAL TEST REPORT

SOLD TO

SHIP TO

CUSTOMER'S PO NO	TYPE OF CERT	CUSTOMER	TECHALLOY ORDER NO.	WORK ORDER	DATE SHIPPED
	Customer	128810	00	0000099221	0/00/00

SPECIFICATIONS: AWS/SFA 5.14

ITEM DESCRIPTION

DESCRIPTION	SPEC. CLASS	HEAT
Techalloy 418	ERNiCU-7	62640
.045" 30Lb Spool 045 A GMAW	QTY SHIP	

CHEMICAL ANALYSIS

NI 65.75	C .06	MO 2.05	P .005	S .001	SI .34	FE .76
TI 2.03	CO .01	AL .10	CU 28.87			

MECHANICAL PROPERTIES

AS WELDED PROPERTIES:

POST WELD HEAT TREAT PROPERTIES:

1/03/01

QC-1

I certify the chemical analysis and physical and mechanical test results reported above are correct as contained in the records of the company.

Very truly yours,
TECHALLOY

AUTHORIZED SIGNATURE

NORCROSS, GA 770-923-3353 FAX 770-923-3709
NORCROSS, GA (WELDING) 770-923-6447 FAX 770-923-9117
UNION, IL 815-923-2131 FAX 815-923-2126
UNION, IL (WELDING) 815-923-2131 FAX 815-923-7242

TECHALLOY Company, Inc.

BALTIMORE, MD 410-633-9300 FAX 410-633-2033
NORTHAMPTON, MA 413-584-3964 FAX 413-584-5288
HOUSTON, TX 713-466-1000 FAX 713-466-7425
PERRIS, CA 909-657-2105 FAX 909-943-5061

BALTIMORE WELDING DIVISION
2310 CHESAPEAKE AVE.
TEL: 410-633-9300
BALTIMORE, MD 21222-4098
FAX: 201-628-1074

CERTIFIED MATERIAL TEST REPORT

SOLD TO	SHIP TO

CUSTOMER'S PO NO.	TYPE OF CERT	CUSTOMER	TECHALLOY ORDER NO.	WORK ORDER	DATE SHIPPED
	Customer	128810	00	0000099221	0/00/00

SPECIFICATIONS: AWS/SFA 5.14

ITEM DESCRIPTION

DESCRIPTION	SPEC. CLASS	HEAT
Techalloy 418	ERNiCu-7	62640
.0450 30Lb Spool 045" Ø GMAW	QTY SHIP	

CHEMICAL ANALYSIS

NI 65.75	C .06	MN 2.05	P .005	S .001	SI .34	FE .76
TI 2.03	CO .01	AL .10	CU 28.87			

MECHANICAL PROPERTIES

AS WELDED PROPERTIES:

POST WELD HEAT TREAT PROPERTIES:

1/23/01

TriNet QC-1 Corporation

I certify the chemical analysis and physical and mechanical test results reported above are correct as contained in the records of the company.

Very truly yours
TECHALLOY

AUTHORIZED SIGNATURE

THE LEADING MANUFACTURER OF STAINLESS STEEL, NICKEL ALLOYS AND WELDING PRODUCTS
EXECUTIVE OFFICES. 370 FRANKLIN TURNPIKE. MAHWAH, NJ 07430-2259 PHONE 201-529-0900 FAX 201-529-1074

NORCROSS, GA 770-923-3353 FAX 770-923-3709
NORCROSS, GA (WELDING) 770-923-6447 FAX 770-923-9117
UNION, IL 815-923-2131 FAX 815-923-2126
UNION, IL (WELDING) 815-923-2131 FAX 815-923-7242

TECHALLOY Company, Inc.
UNION GROUP

BALTIMORE, MD 410-633-9300 FAX 410-633-2033
NORTHAMPTON, MA 413-584-3984 FAX 413-584-5288
HOUSTON, TX 713-466-1000 FAX 713-466-7425
PERRIS, CA 909-657-2105 FAX 909-943-5081

BALTIMORE WELDING DIVISION
2310 CHESAPEAKE AVE.
TEL: 410-633-9300
BALTIMORE, MD 21222-4098
FAX: 201-529-1074

CERTIFIED MATERIAL TEST REPORT

SOLD TO

SHIP TO

CUSTOMER'S PO NO.	TYPE OF CERT	CUSTOMER	TECHALLOY ORDER NO.	WORK ORDER	DATE SHIPPED
003472	Customer	128810	00	0000096311	0/00/00

SPECIFICATIONS: AWS/SFA 5.11
BATCH# 025860

ITEM DESCRIPTION

DESCRIPTION	SPEC. CLASS	HEAT
Tech-Rod M190	ENICU-7	M32J8G
.1250 10#Met Can 1/8" SMAW	QTY SHIP 60.000	

CHEMICAL ANALYSIS

CU 28.68	C .026	MN 3.91	P .010	S .006	SI 1.16	FE 1.44
TI .30	CO .01	AL .06	NI 64.38			

MECHANICAL PROPERTIES

AS WELDED PROPERTIES.

POST WELD HEAT TREAT PROPERTIES:

9/18/00

I certify the chemical analysis and physical and mechanical test results reported above are correct as contained in the records of the company.
Very truly yours,
TECHALLOY

AUTHORIZED SIGNATURE

FormSource Form CTR706 8/15/99

THE LEADING MANUFACTURER OF STAINLESS STEEL, NICKEL ALLOYS AND WELDING PRODUCTS
TRI
EXECUTIVE OFFICES: 370 FRANKLIN TURNPIKE, MAHWAH, NJ 07430-2259 PHONE 201-529-0900 FAX 201-529-1074

NORCROSS, GA 770-923-3353 FAX 770-923-3709
NORCROSS, GA (WELDING) 770-923-6447 FAX 770-923-9117
UNION, IL 815-923-2131 FAX 815-923-2126
UNION, IL (WELDING) 815-923-2131 FAX 815-923-7242

TECHALLOY Company, Inc.
USINOR GROUP

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HOUSTON, TX 713-466-1000 FAX 713-466-7425
PERRIS, CA 909-657-2105 FAX 909-943-5061

BALTIMORE WELDING DIVISION
2310 CHESAPEAKE AVE.
TEL: 410-633-9300
BALTIMORE, MD 21222-4098
FAX: 201-529-1074

CERTIFIED MATERIAL TEST REPORT

SOLD TO

Nu-Tech Precision Metals
P.O# 33350
P.S# 017481
Weight-10lbs
03/05/2001

SHIP TO

CUSTOMER'S PO NO.	TYPE OF CERT	CUSTOMER	TECHALLOY ORDER NO.	WORK ORDER	DATE SHIPPED
	Customer	128810	00	0000094970	0/00/00

SPECIFICATIONS: AWS/SFA 5.11
BATCH#022830

ITEM DESCRIPTION

DESCRIPTION	SPEC. CLASS	HEAT
Tech-Rod M190	ENICU-7	M26J2G
.1563 10#Met Can 5/32 @ SMAW	QTY SHIP	

CHEMICAL ANALYSIS

NI 63.78	C .030	MN 3.59	P .008	S .005	SI 1.15	FE 1.34
TI .48	CO .04	AL .071	CU 29.49			

MECHANICAL PROPERTIES

AS WELDED PROPERTIES:

POST WELD HEAT TREAT PROPERTIES:

8/18/00

TruNex QC-1 Certified

I certify the chemical analysis and physical and mechanical test results reported above are correct as contained in the records of the company.

Very truly yours,
TECHALLOY

AUTHORIZED SIGNATURE

FormSpec Form - CERTDS 6/15/98

EXECUTIVE OFFICES 370 FRANKLIN TURNPIKE, MAHWAH, NJ 07430-2259 PHONE 201-529-0900 FAX 201-529-1074

NORCROSS, GA 770-923-3353 FAX 770-923-3709
NORCROSS, GA (WELDING) 770-923-6447 FAX 770-923-9117
UNION, IL 815-923-2131 FAX 815-923-2126
UNION, IL (WELDING) 815-923-2131 FAX 815-923-7242

TECHALLOY Company Inc.
USINOR GROUP

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HOUSTON, TX 713-466-1000 FAX 713-466-7425
PERRIS, CA 909-657-2105 FAX 909-943-5061

BALTIMORE WELDING DIVISION
2310 CHESAPEAKE AVE.
TEL: 410-633-9300

BALTIMORE, MD 21222-4098
FAX: 201-529-1074

CERTIFIED MATERIAL TEST REPORT

SOLD TO

Nu-Tech Precision Metals
P.O# 33350
P.S# 017481
Weight-10lbs
03/05/2001

SHIP TO

CUSTOMER'S PO NO.	TYPE OF CERT	CUSTOMER	TECHALLOY ORDER NO.	WORK ORDER	DATE SHIPPED
003265	Customer	128810	00	0000092860	0/00/00

SPECIFICATIONS: AWS/SFA 5.11
BATCH# 018120

ITEM DESCRIPTION

DESCRIPTION	SPEC. CLASS	HEAT
Tech-Rod M190	ENICU-7	M26J2G
.1875 10 Lb Cans 3/16ø SMAW	QTY SHIP 90.000	

CHEMICAL ANALYSIS

NI 64.52	C .027	MN 3.29	P .009	S .006	SI 1.12	FE 1.28
TI .78	CO .03	AL .076	CU 28.85			

MECHANICAL PROPERTIES

AS WELDED PROPERTIES:

POST WELD HEAT TREAT PROPERTIES:

6/30/00

I certify the chemical analysis and physical and mechanical test results reported above are correct as contained in the records of the company.

Very truly yours,
TECHALLOY

AUTHORIZED SIGNATURE

AgentSpace Form: CERTS, 6/15/99

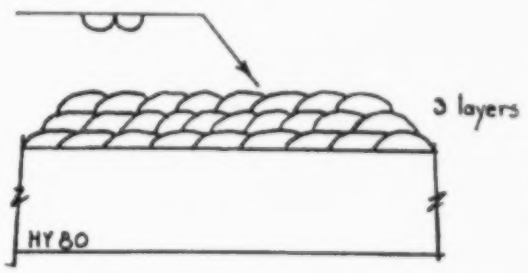
APPENDIX B

Shielded Metal Arc Welding (SMAW)
and
Pulsed Gas Metal Arc Welding (P-GMAW)
Procedure Specifications

WELDING PROCEDURE SPECIFICATION (WPS)

Project No: 40-1613
PQR No.: SMAW MONEL OVERLAY

Material Specification: ERNiCu-7 overlay on HY80 Steel
Welding Process/Equip.: SMAW
Manual or Machine: Machine assisted manual
Position of Welding: 1G
Filler Metal: ERNiCu-7 (Techalloy M190)
Shielding Gas: – Flow Rate: –
Auxiliary Shielding: – Flow Rate: –
Material Thickness: HY80 @ 25mm
Single or Multipass: multipass/multilayer
Tungsten: –
Preheat Temperature: 21°C
Interpass Temperature: 125°C maximum
Preheat Method: –
Root Treatment: machined surface



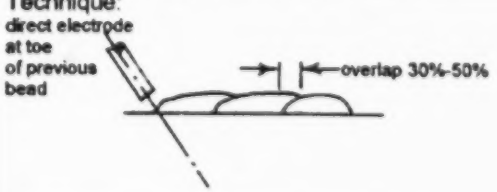
Joint Preparation

ID	SIDE	Layer	Pass No.	Machine Settings				Travel mm/min	V	WFS (dial)	TTWD (mm)	Electrode Size (mm)	Comments/Results
				Ip (amps)	Ip on (%)	Ib (%)	Freq (PPS)						
1	1	1-3	All	95				152				3.2	
2	1	1-3	All	130				152				4.0	
3	1	1-3	All	165				152				5.0	

Procedure Notes:

- use stringer bead technique with minimum weave
- maintain a moderate tight arc (not dragging)

Technique:

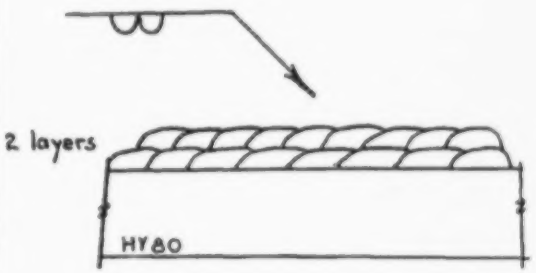


Date	Welder's Name:	Inspected By:	Procedure By
March 2001	Blane Larone	Kevin G. Mornson	Kevin G. Morrison

WELDING PROCEDURE SPECIFICATION (WPS)

Project No: 40-1613
PQR No.: P-GMAW MONEL OVERLAY

Material Specification: ERNiCu-7 overlay on HY80 Steel
Welding Process/Equip.: Miller Maxtron 450/64M/Bernard WC
Manual or Machine: Guilco Kat/Track/Oscillator
Position of Welding: 1G
Filler Metal: ENiCu-7 (Techalloy 418)
Shielding Gas: Ar/He 25% Flow Rate: 20 - 30 lpm
Auxiliary Shielding: Ar Flow Rate: 20 - 30 lpm
Material Thickness: HY80 @ 25mm
Single or Multipass: multipass/2 layers
Tungsten: –
Preheat Temperature: 21°C
Interpass Temperature: 125°C maximum
Preheat Method: NA
Root Treatment: machined surface



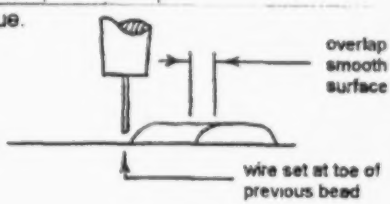
Joint Preparation

ID	SIDE	Layer	Pass No.	Machine Settings				Travel mm/min	V (Trim)	WFS m/min	TTWD (mm)	Electrode Size (inches)	Comments/Results
				Ip (amps)	Ip on (%)	Ib (%)	Freq (PPS)						
150/5	1	1-2	All	•	•	•	•	152	40	3.81	16	0.045	oscillation width = 7mm
													oscillation speed = 5 dial
225/10	1	1-2	All	•	•	•	•	254	86	5.72	16	0.045	oscillation width = 7mm
													oscillation speed = 5 dial
225/16	1	1-2	All	•	•	•	•	406	86	5.72	16	0.045	no oscillation

Procedure Notes:

- Miller 64M Feeder - *Program 2/Adaptive
- arc length set approximately 3.0mm above molten puddle with no spatter
- trailing shield used
- no hesitation used with oscillation

Technique:



Date:	Welder's Name:	Inspected By:	Procedure By:
March 2001	Blane Larone	Kevin G. Morrison	Kevin G. Morrison

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Nu-Tech Precision Metals Inc.,
Joining Technology Division
460 McCartney Street, PO Box 7, Amprior, ON K7S 3H2

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Weld Cladding of HY-80 Steel With Monel

4 AUTHORS (Last name, first name, middle initial If military, show rank, e g Doe, Maj John E.)

Morrison, Kevin G.

5 DATE OF PUBLICATION (month and year of publication of document)

July 2001

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25(approx.)

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Defence Research Establishment Atlantic
PO Box 1012
Dartmouth, NS, Canada B2Y 3Z7

9a PROJECT OR GRANT NO (if appropriate, the applicable research and development project or grant number under which the document was written Please specify whether project or grant)

1GH16

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Weld Cladding of HY-80 Steel With Monel
by
Kevin G. Morrison

To produce specimens for the evaluation of dilution effects in Monel cladding of HY-80 steel, shielded metal arc and gas metal arc welding were used to clad coupons of HY-80 with Monel. A range of dilutions from less than 3% iron to in excess of 15% iron were achieved. Monel sheets were welded around the unclad faces of some coupons, to produce specimens suitable for long-term corrosion studies without galvanic effects.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document They should be selected so that no security classification is required Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included If possible keywords should be selected from a published thesaurus e g Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified If it not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title)

- HY-80
- gas metal arc welding
- shielded metal arc welding
- Monel
- cladding